TENSION FRACTURING AT URANIUS FOSSAE, MARS.

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SUMMARY

Uranius Fossae is a series of cross-cutting grabens of various directions, in which three preferential trends are found. It is suggested that crustal uplift associated to unsteady stress trajectories may have produced tension fractures. After they reached a critical depth, they changed to normal faults, and tensile stress concentration at surface at some distance from the faults produced antithetic faulting. This mechanism may also apply to other fractured terrains on Mars.

INTRODUCTION

Several old fractured terrains in the Tharsis province have been poorly studied. They include Ulysses and Uranius Fossae, and a small area south of Valles Marineris (north of Solis Dorsa, called "Solis Fossae" below). Although the origin of fracturing in these regions may differ, a common feature is that these terrains are windows of highly fractured Noachian or lower Hesperian terrains outcroping under lava flows erupted later, during the main phases of Tharsis volcanic activity [1]. They are thus witnesses of some of the oldest deformations that occurred in this area of Mars.

Although the available topography is not accurate, it appears that part of Ulysses Fossae may be more than 1 km higher than the surrounding terrains [2, 3]. Uranius Fossae seems to be located on a smaller topographic height. This elevation is probably the reason why these terrains were not subsequently covered by lava flows. It suggests early crustal bending, which is confirmed by geometric analysis and mechanical interpretation of Uranius Fossae.

GEOMETRIC ANALYSIS

Four episodes of faulting during Noachian and Hesperian were found at Ulysses Fossae, corresponding to 4 distinct fault orientations [4]. Figure 1 (top) shows structural mapping of Uranius Fossae. Analysis was focused on graben strikes in order to determine if different trends can be separated. Graben length, width, and depth were not considered.

Graben azimuth was measured and plotted (figure 1, bottom). Many grabens are arcuate, so that attributing a single azimuth to each one would have not made sense; rather, grabens following more than one trend were measured more than once. Although there is a large scattering in azimuth distribution, three orientations are best represented: N005W-N005E, N010E-N025E, and N030W-N040E.

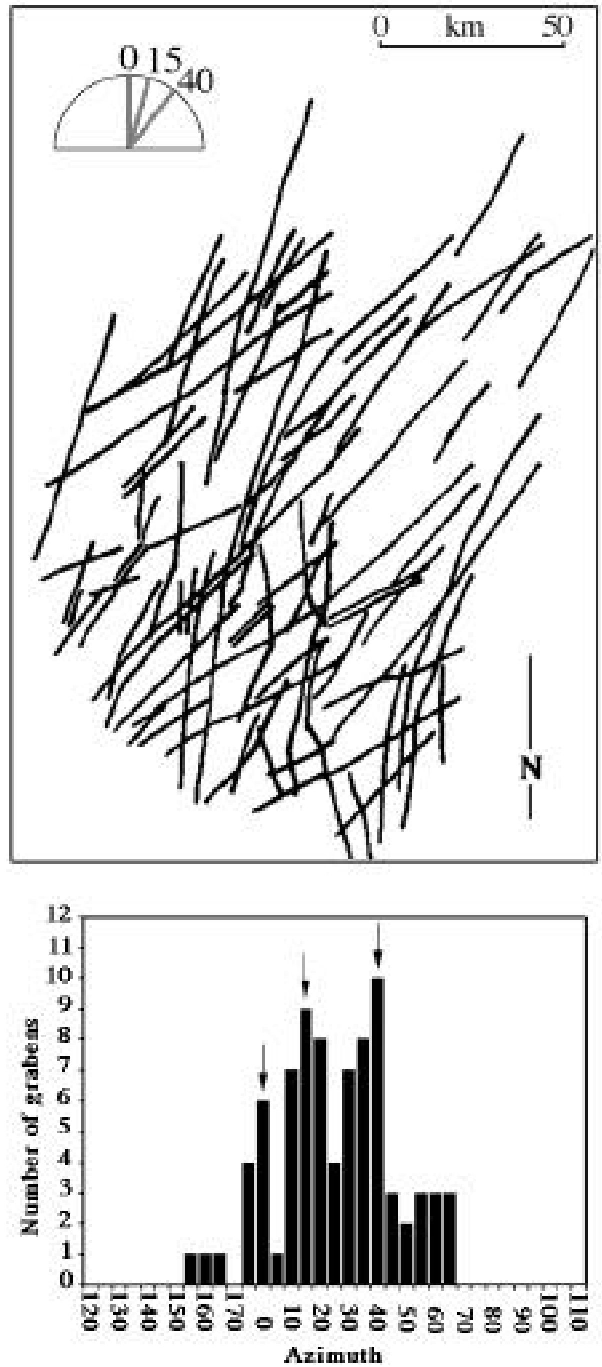

Figure 1 - Graben mapping and azimuth-frequency plot of Uranius Fossae.

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MECHANICAL INTERPRETATION

Tension fracturing

Cross-cutting extensional structures similar to those at Uranius Fossae are observed on Earth in numerous places, such as north-east of the Gulf of Aqaba (e.g., [5, 6]). These structures are pure tension fractures up to 100 km long. Nur [6] reviewed several possible mechanisms of fracture formation, and concluded that tectonic uplift (crustal bending) is the most likely origin of these lineaments. Observation of distinct fracture sets is correlated to variations in orientation of principal stresses, and depends on the ratio of the tension fracture strength *S* to the tensile strength of the unfractured rock *T* [6]. The first fracture set F1 forms perpendicular to the least compressive stress σ_3^1. A second fracture set F2 will develop during a further tectonic event if the angle between σ_3^1 and the least compressive stress during the new tectonic event σ_3^2 is larger than a critical angle φc, where

$$\varphi c = \cos^{-1}(S/T)^{1/2}$$

A smaller angle would cause reopening of F1. For instance, if fractures F1 have no strength, F2 will form only if σ_3^2 is perpendicular to σ_3^1; conversely, if fractures F1 are healed, F2 will develop for angles between σ_3^1 and σ_3^2 inversely proportional to the level of healing. Application to Uranius Fossae suggests that the tectonic activity during early local crustal bending may have resulted in the formation of tension fractures, the strength of which cannot be neglected., prior to the formation of normal faults.

Normal faulting

It results from the Griffith failure criterion in tensile regime that normal fault nucleation on tension fractures occurs when the tension fractures reach a critical depth Zmax, defined by

$$Zmax = 3T/\rho g$$

where ρ is crustal density and g the acceleration of gravity [7]. Taking *T* to be a few MPa, ρ = 2.8, and g = 3.71 m/s^{-2}, fault nucleation is expected to occur on Mars after tension fracture depth has reached a few hundred meters to some 2 or 3 kilometers (figure 2), deeper than on Earth.

Graben formation

Once normal faulting has been initiated, fault movement is expected to favour initiation of secondary faults. It was shown that antithetic faulting will require less energy than synthetic faulting in homogeneous elastic crust undergoing pure tension [8]. It may be reasonable to assume that the Tharsis crust was still rather homogeneous when Uranius Fossae formed, and if the stress regime during tension fracturing and subsequent faulting did not change significantly, this result should apply to Uranius Fossae. Formation of each tension fracture set would then be followed by graben formation, before the formation of another fracture set.

The distance between graben border faults at surface may be indicative of the maximum depth reached by the first fault [8]. Graben width in Uranius Fossae is generally of the order of 2 kilometers, suggesting that the maximum depth of tension fractures on which faults nucleated should have been of the order of 2 km at most.

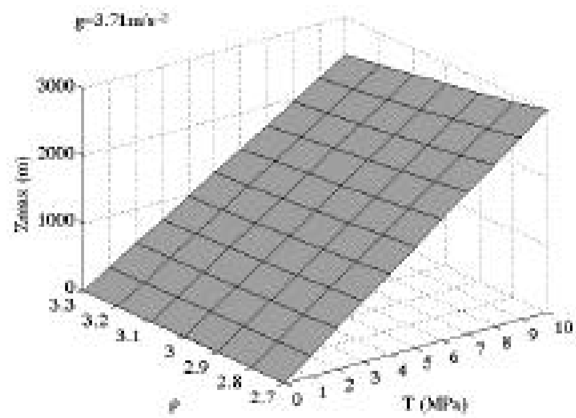

Figure 2 - Maximum depth reached by tension fractures on Mars according to Griffith's failure criterion in tension.

CONCLUSION

Formation of Uranius Fossae may have been induced by early crustal bending at the very beginning of Tharsis formation. Bending can explain the complexity of the structures observed, and suggests that tension fracturing occurred prior to normal faulting and graben development. Existence of non-null fracture strength, maybe resulting from cementation due to hydrothermal activity, or from rock-bridge strength between fracture segments, explains why the unsteady stress trajectories during bending produced tension fractures, and then grabens, following a few preferential directions. The mechanism presented here may be valid for other old fractured terrains in the Tharsis province, including Ulysses Fossae and Solis Fossae.

References: [1] Scott, D. H., and K. L. Tanaka, 1986, U. S. Geol. Surv. Misc. Invest. Series, I-1802-A. [2] U. S. Geol. Surv., 1991, Misc. Invest. Ser., I-2111. [3] U. S. Geol. Surv., 1991, Misc. Invest. Ser., I-2160. [4] Scott, D. H., and J. M. Dohm, 1990, Proc. 20th Lunar Planet. Sci. Conf., 503-513. [5] Hall, J. K., 1994, Digital Shaded-Relief map of Israel and environs, Geol. Surv. Israel. [6] Nur, A., 1982, J. Struct. Geol., 4, 31-40. [7] Gudmundsson, A., 1992, Terra Nova, 4, 464-471. [8] Melosh, H. J., and C. A. Williams, Jr., 1989, J. Geophys. Res., 94, 13961-13973.